

WORK STATEMENT

Engine CHP Emission Control Technology

Introduction

Combined Heat and Power (CHP) has become an important element of California's energy and environmental policy and is prominent in the California Energy Commission (Energy Commission) 2005 Integrated Energy Policy Report (IEPR), California's Energy Action Plan (EAP), and California's Climate Action Team Report (CATR).

Reciprocating engines have historically been the preferred prime mover for CHP applications less than 3 MW in size due to their favorable cost and efficiency characteristics. A recent CHP market assessment sponsored by the Energy Commission concluded that reciprocating engines will continue to be the prime mover of choice for a large majority of CHP applications in California through the year 2020.

Yet, a number of obstacles continue to impede the adoption of CHP in the State including rate design, non-quantification of grid benefits, interconnection expense, and tightening emission requirements. This proposal addresses looming emission regulations that are challenging emission control technology for natural gas reciprocating engines. Specifically, there are two regulatory actions that define the quandary: 1) California Air Resources Board's (CARB's) *Electrical Generation Technologies Guidance Document* that recommends natural gas distributed generation (DG) be required to achieve new combined cycle plant emission levels by 2007 (CARB 2007); and 2) South Coast Air Quality Management District (SCAQMD) DG Rulemaking that would implement CARB 2007 and establish rigorous and costly emission compliance protocols for engines < 1,000 hp.

Project Description

Features of emission control technology strategies and attributes of onboard diagnostics (OBD II) currently deployed by the automotive industry will be adapted and developed for use in natural gas engines in CHP applications. The emission system will include precise air/fuel (A/F) ratio controllers, a robust 3-way catalyst (TWC), oxygen sensors on either side of the 3-way catalyst, control software, diagnostics and alarms. The emissions system may include an oxidation catalyst in combination with a mechanism to induce air flow into the exhaust prior to the oxidation catalyst. The technology will be applicable to rich burn and cooled exhaust gas recirculation (EGR) engines less than 1,000 kW in size.

Project Goals

To develop and test ultra clean emission technology for small to medium (60 – 1,000 kW) engine CHP systems that 1) exceeds CARB 2007 emission guidelines; 2) provides control techniques for robust CARB 2007 emission compliance on a sustainable basis without the need for frequent hand held emission analyzer tests; and 3) has a cost premium less than 10 percent of existing CHP systems.

Project Duration

The project will be completed in forty-four months from work initiation.

TASK LIST SUMMARY

Task #	CPR	Task Name
1		Administration
2		Control Software and Component screening
3		Test Plan Preparation
4	X	Laboratory Performance Testing
5		Field Verification
6		Technology Transfer Activities

TASK 1 ADMINISTRATION**Task 1.1 Attend Kick-off Meeting**

The goal of this task is to establish the lines of communication and procedures for implementing this Agreement.

The Recipient shall:

Attend a “kick-off” meeting with the Commission Project Manager, the Grants Officer, and a representative of the Accounting Office. The Recipient shall bring their Project Manager, Contracts Officer, Accounting Officer, and others designated by the Commission Project Manager to this meeting. The administrative and technical aspects of this Agreement will be discussed at the meeting. Prior to the kick-off meeting, the Commission Project Manager will provide an agenda to all potential meeting participants.

The administrative portion of the meeting shall include, but not be limited to, the following:

- Terms and Conditions of the Agreement
- CPRs (Task 1.2)
- Match Fund Documentation (Task 1.6)
- Permit Documentation (Task 1.7)

The technical portion of the meeting shall include, but not be limited to, the following:

- The Commission Project Manager’s expectations for accomplishing tasks described in the Scope of Work;
- An updated Schedule of Products
- An updated Gantt Chart
- Progress Reports (Task 1.4)
- Technical Products (Special Conditions)
- Final Report (Task 1.5)

The Commission Project Manager shall designate the date and location of this meeting.

Products:

- Schedule of Products
- Gantt Chart
- List of Match Funds
- List of Permits, if applicable

Due Date: June 16, 2007

Task 1.2 CPR Meetings

The goal of this task is to determine if the project should continue to receive Commission funding to complete this Agreement and if it should, are there any modifications that need to be made to the tasks, products, schedule or budget.

CPRs provide the opportunity for frank discussions between the Commission and the Recipient. CPRs generally take place at key, predetermined points in the Agreement, as determined by the Commission Project Manager and as shown in the Technical Task List above and in the Schedule of Products. However, the Commission Project Manager may schedule additional CPRs as necessary, and any additional costs will be borne by the Recipient.

Participants include the Commission Project Manager and the Recipient, and may include the Commission Grants Officer, the PIER Program Team Lead, other Commission staff and Management as well as other individuals selected by the Commission Project Manager to provide support to the Commission.

The Commission Project Manager shall:

- Determine the location, date and time of each CPR meeting with the Recipient. These meetings generally take place at the Commission, but they may take place at another location.
- Send the Recipient the agenda and a list of expected participants in advance of each CPR. If applicable, the agenda shall include a discussion on both match funding and permits.
- Conduct and make a record of each CPR meeting. One of the outcomes of this meeting will be a schedule for providing the written determination described below.
- Determine whether to continue the project, and if continuing, whether or not to modify the tasks, schedule, deliverables and budget for the remainder of the Agreement, including not proceeding with one or more tasks. If the Commission Project Manager concludes that satisfactory progress is not being made, this conclusion will be referred to the Energy Commission's Research, Development and Demonstration Policy Committee for its concurrence.

- Provide the Recipient with a written determination in accordance with the schedule. The written response may include a requirement for the Recipient to revise one or more product(s) that were included in the CPR.

The Recipient shall:

- Prepare a CPR Report for each CPR that discusses the progress of the Agreement toward achieving its goals and objectives. This report shall include recommendations and conclusions regarding continued work of the projects. This report shall be submitted along with any other products identified in this Scope of Work. Submit these documents to the Commission Project Manager and any other designated reviewers at least 15 working days in advance of each CPR meeting.
- Present the required information at each CPR meeting and participate in a discussion about the Agreement.

Recipient Products:

- CPR Report(s)
- CPR products identified in the Scope of Work

Commission Project Manager Products:

- Agenda and a List of Expected Participants
- Schedule for Written Determination
- Written Determination

Due Date: ~~September 30, 2009~~ **November 17, 2009**

Task 1.3 Final Meeting

The goal of this task is to closeout this Agreement.

The Recipient shall meet with the Commission to present the findings, conclusions, and recommendations. The final meeting must be completed during the closeout of this Agreement.

This meeting will be attended by, at a minimum, the Recipient, the Commission Grants Officer, and the Commission Project Manager. The technical and administrative aspects of Agreement closeout will be discussed at the meeting, which may be two separate meetings at the discretion of the Commission Project Manager.

The technical portion of the meeting shall present findings, conclusions, and recommended next steps (if any) for the Agreement. The Commission Project Manager will determine the appropriate meeting participants.

The administrative portion of the meeting shall be a discussion with the Commission Project Manager and the Grants Officer about the following Agreement closeout items:

- What to do with any equipment (Options)
- Commission's request for specific "generated" data (not already provided in Agreement deliverables)

- Need to document Recipient's disclosure of "subject inventions" developed under the Agreement
- "Surviving" Agreement provisions, such as repayment provisions and confidential products
- Final invoicing and release of retention

The Recipient shall prepare a schedule for completing the closeout activities for this Agreement.

Products:

- Written documentation of meeting agreements and all pertinent information
- Schedule for completing closeout activities

Due Date: ~~October 31, 2010~~ **May 31, 2011**

Task 1.4 Monthly Progress Reports

The goal of this task is to periodically verify that satisfactory and continued progress is made towards achieving the research objectives of this Agreement.

The Recipient shall:

Prepare progress reports which summarize all Agreement activities conducted by the Recipient for the reporting period, including an assessment of the ability to complete the Agreement within the current budget and any anticipated cost overruns. Each progress report is due to the Commission Project Manager within 5 working days after the end of the reporting period. The terms and conditions of this Agreement provide the recommended specifications.

Products: Monthly Progress Reports

Due Date: By the 10th day of each month during the approved term of this Agreement or until submission of the final report.

Task 1.5 Final Report

The goal of the Final Report is to assess the project's success in achieving its goals and objectives, advancing science and technology, and providing energy-related and other benefits to California.

The objectives of the Final Report are to clearly and completely describe the project's purpose, approach, activities performed, results, and advancements in science and technology; to present a public assessment of the success of the project as measured by the degree to which goals and objectives were achieved; to make insightful observations based on results obtained; to draw conclusions; and to make recommendations for further RD&D projects and improvements to the PIER project

management processes.

The Final Report shall be a public document. If the Recipient has obtained confidential status from the Energy Commission and will be preparing a confidential version of the Final Report as well, the Recipient shall perform the following activities for both the public and confidential versions of the Final Report.

The Recipient shall:

- Prepare an Outline of the Final Report.
- Prepare a Final Report following the approved outline and the latest version of the PIER Final Report guidelines published on the Energy Commission's website at <http://www.energy.ca.gov/contracts/pier/contractors/index.html> at the time the Recipient begins performing this task, unless otherwise instructed in writing by the Commission Project Manager. Instead of the timeframe listed in the Product Guidelines located in Section 5 of the Terms and Conditions, the Commission Project Manager shall provide written comments on the Draft Final Report within fifteen (15) working days of receipt. The Final Report must be completed on or before the end of the Agreement Term.
- Submit one bound copy of the Final Report with the final invoice.

Products:

- Draft Outline of the Final Report
- Final Outline of the Final Report
- Draft Final Report
- Final Report

Due Date: May 31, 2010 **April 29, 2011**

Task 1.5.2 Final Report

The Recipient shall:

- ~~Prepare the draft Final Report for this Agreement in accordance with the approved outline.~~
- ~~Submit the draft Final Report to the Commission Project Manager for review and comment. The Commission Project Manager will provide written comments within 10 working days of receipt. Once agreement on the draft Final Report has been reached, the Commission Project Manager shall forward the electronic version of this report to the Commission Project Manager for final editing. Once final editing is completed, the Commission Project Manager shall provide written approval to the Recipient within 2 working days.~~
- ~~Submit one bound copy of the Final Report with the final invoice.~~

Products:

- ~~Draft Final Report~~
- ~~Final Report~~

Due Date: ~~August 31, 2010~~

Task 1.6 Identify and Obtain Matching Funds

The goal of this task is to ensure that the match funds planned for this Agreement are obtained for and applied to this Agreement during the term of this Agreement.

The costs to obtain and document match fund commitments are not reimbursable through this Agreement. While the PIER budget for this task will be zero dollars, the Recipient may utilize match funds for this task. Match funds shall be spent concurrently or in advance of PIER funds during the term of this Agreement. Match funds must be identified in writing, and the associated commitments obtained, prior to the Energy Commission providing reimbursement for any costs incurred under this Agreement.

The Recipient shall:

- Prepare a letter documenting the match funding committed to this Agreement and submit it to the Commission Project Manager at least 2 working days prior to the kick-off meeting. The letter shall include a list of the match funds that identifies the:
 - Amount of each cash match fund, its source, including a contact name, address and telephone number and the task(s) to which the match funds will be applied.
 - Amount of each in-kind contribution, a description, documented market or book value, and its source, including a contact name, address and telephone number and the task(s) to which the match funds will be applied. If the in-kind contribution is equipment or other tangible or real property, the Recipient shall identify its owner and provide a contact name, address and telephone number, and the address where the property is located.
- Provide a copy of the letter of commitment from an authorized representative of each source of cash match funding or in-kind contributions that these funds or contributions have been secured.
- Discuss match funds and the implications to the Agreement if they are significantly reduced or not obtained as committed at the kick-off meeting. If applicable, match funds will be included as a line item in the progress reports and will be a topic at CPR meetings.
- Provide the appropriate information to the Commission Project Manager if during the course of the Agreement additional match funds are received.
- Notify the Commission Project Manager within 5 working days if during the course of the Agreement existing match funds are reduced. Reduction in match funds may trigger an additional CPR.

Products:

- A letter documenting Match Funds
- A copy of each Match Fund commitment letter

Due Date: December 31, 2007

Product: Letter documenting change in match share and copy of commitment letter (if applicable)

Due Date: As necessary, within 10 days of change in match share commitment.

Task 1.7 Identify and Obtain Required Permits

The goal of this task is to obtain all permits required for work completed under this Agreement in advance of the date they are needed to keep the Agreement schedule on track.

Permit costs and the expenses associated with obtaining permits are not reimbursable under this Agreement. While the PIER budget for this task will be zero dollars, the Recipient shall show match funds for this task. Permits must be identified in writing and obtained before the Recipient can incur any costs related to the use of the permits for which the Recipient will request reimbursement.

The Recipient shall:

Prepare a letter documenting the permits required to conduct this Agreement and submit it to the Commission Project Manager at least 2 working days prior to the kick-off meeting:

1. If there are no permits required at the start of this Agreement, then state such in the letter.
2. If it is known at the beginning of the Agreement that permits will be required during the course of the Agreement, provide in the letter:
 - Type(s) of permit(s)
 - Name, address and telephone number of the permitting jurisdictions or lead agencies
 - Schedule the Recipient will follow in applying for and obtaining these permits

The list of permits and the schedule for obtaining them will be discussed at the kick-off meeting and a timetable for submitting the updated list, schedule and the copies of the permits will be developed. The implications to the Agreement if the permits are not obtained in a timely fashion or are denied will also be discussed. If applicable, permits will be included as a line item in the progress reports and will be a topic at CPR meetings.

If during the course of the Agreement additional permits become necessary, then provide the appropriate information on each permit and an updated schedule to the Commission Project Manager.

As permits are obtained, send a copy of each approved permit to the Commission Project Manager.

If during the course of the Agreement permits are not obtained on time or are denied, notify the Commission Project Manager within 5 working days. Either of these events may trigger an additional CPR.

Product: Letter documenting the Permits or stating that no Permits are required
Due Date: April 30, 2009

Product: Updated list of permits as they change during the approved term of the Agreement
Due Date: As necessary, within 10 days of change

Product: A copy of each approved Permit
Due Date: As necessary, within 10 days of receipt of each permit

TECHNICAL TASKS

TASK 2 CONTROL SOFTWARE AND COMPONENT SCREENING

The goal of this task is to identify automotive emission control software platforms, and air/fuel ratio and exhaust after-treatment components that show the best potential for reaching CARB 2007 emission targets when adapted to operate on stationary, natural gas-powered engines.

The Recipient shall:

- Review state-of-the-art emission control system components and methods. Evaluate these components and methods for suitability for small- to medium-sized natural gas engines. Components and methods that will be screened include:
 - Three Way Catalysts (TWC);
 - Oxidation catalysts and methods for air injection;
 - Narrow- and wide-band O₂ sensors;
 - Air/fuel ratio controllers; and,
 - High energy ignition systems
- Profile the performance of candidate components based on:
 - Manufacturer specifications and cost
 - Reconnaissance on performance, degradation, durability, drift, control, ease and frequency of maintenance, manufacturer's ability to support the project, and other non-emissions related attributes; and,
 - Selective laboratory examination if warranted.

- Screen components and suppliers for components and methods that warrant detailed evaluation.
- Develop initial control software to operate the candidate components that will be evaluated and tested for the stationary, natural gas-powered engines.

Products:

- Draft Component Screening Report summarizing the findings of the above mentioned control software and component screening activities.
- Final Component Screening Report summarizing the findings of the above mentioned control software and component screening activities.

Due Date: ~~July 31, 2009~~ **September 30, 2010**

TASK 3 TEST PLAN PREPARATION

The goal of this task will be to describe the methodology, instrumentation and measurements for measuring quantitative performance goals and for providing design feedback to adjust and fine tune the emission system configuration and control algorithms. To accomplish this task the recipient will specify monitoring equipment and techniques to verify emission system and component performance for factory/laboratory testing and for field testing.

Specific components and systems to be tested will be described along with methods to be employed to measure performance relative to the overall project goals. Laboratory tests and field verification tests will be performed to fine tune performance control and to ensure robust performance over a range of field conditions. The laboratory test plan and the field verification test plan will describe the methodology, instrumentation and measurements for measuring quantitative performance goals and to facilitate system optimization and control system functionality. The test plans will follow appropriate ASERTTI DG test protocols relevant to measurement and accomplishment of project performance goals.

The Recipient shall:

- Explain the nature and the goals of the component and system tests to be performed. Specific components to be tested include narrow-band and wide-band O₂ sensors, air/fuel ratio controls, catalysts, high energy ignition systems, exhaust gas recirculation, software algorithms, and alarms. The effect of oil blowby and consumption on emissions will also be examined.
- Describe the methodologies and instrumentation to be instituted in the performance of each component and system test series.

Product: Draft and Final Laboratory Test Plan
Due Date: ~~April 30, 2009~~ **February 26, 2010**

Product: Draft and Final Field Test Plan
Due Date: ~~June 30, 2009~~ **July 30, 2010**

TASK 4 LABORATORY PERFORMANCE TESTING

The goals of this task will be to:

- 1) Characterize component and emission system performance for the Tecogen 7.4 liter engine over a range of operating conditions
- 2) Maximize functionality of emission system to achieve CARB 2007 emissions with minimal sacrifice to CHP system performance and cost.

The test sequences described below are expected to lead to a most-desired combination of electromechanical components, catalysts, and algorithms. While some software development will occur prior to the first tests, it is expected that many of the finer points of algorithm development will occur during the performance of the tests noted above. Algorithm development will occur in the area of air/fuel ratio management as well as in the area of self diagnostic capability. Diagnostic alarms may be developed based on catalyst differential temperature, O2 sensor anomalies, and monitoring of differences between open loop baselines and the extent of closed-loop adjustments. The final configuration will be incorporated into field test units for Task 5.

The Recipient shall:

Procure instrumentation and up fit the test cell, as described in the Test Plan (Task 3) as necessary. The laboratory test facilities will be configured around Tecogen's 100 kW inverter based engine system (InVerde 100). The engine will be enabled to run at any speed and load profile so that operating conditions typical of Tecogen's cogeneration products can be tested. The test cell will be configured to allow easy retrofit of components. An exhaust gas recirculation (EGR) system to return cooled exhaust gas to the engine will be installed.

The new test cell will also be equipped with the ability to inject atomized oil into the engine to mimic the effect of increased oil blow-by caused by engine aging.

In addition, the existing fleet of traditional Tecogen CM-75 units (75 kW) in Southern California that have been retrofitted with double O2 sensors and controls will be used as an in situ or virtual laboratory to capture the effects of aging and varied field conditions on the ability to correct for O2 sensor drift and maintain emission compliance, albeit the emission requirements are not as stringent as CARB 2007.

The following activities will be conducted:

- Perform a series of tests designed to address short-term, medium-term, and long-term emissions control issues surrounding the air/fuel ratio control and catalyst system as outlined in the Test Plan developed in Task

3. Short-term considerations include the raw ability of the emissions control system to achieve the target NO_x, CO, and VOC levels over a range of engine loads. Medium-term considerations include the ability of the system to maintain the desired emissions levels consistently after multiple start-stop cycles, after changes in day-to-day ambient condition, and simply day-to-day. Long-term issues to address include the robustness of the emissions control performance with regards to catalyst aging, multiple catalyst cleaning cycles, and oxygen sensor aging and field replacement. Specific test activities likely to occur may include:

- Collect historical emission data on traditional units operating in Southern California with double O₂ sensor emission controls. Document the schedule for catalyst and sensor change-outs.
- Characterize the aging effect of O₂ sensors and catalysts by characterizing the NO_x and CO reducing performance as sensor and catalyst age. Use the data to confirm or fine-tune the correlation between downstream narrow-band and wide-range O₂ sensor output and emissions excursions for use in the advanced emission system including alarming strategies.
- Determine the optimum EGR rate which lowers NO_x production without severely impacting engine peak power.
- Characterize the effect of oil consumption on emissions and determine appropriate technical fixes and optimal engine rebuild timing in environmentally stringent markets.
- Generate dithering and non-dithering air/fuel ratio control strategies and characterize the emissions performance capability of both.
- Oxidation catalyst testing. Test the mechanisms designed to induce air flow into the exhaust for downstream oxidation. Define the additional benefit gained by the oxidation catalyst over the upstream TWC. Define flexibility gained by inclusion of an oxidation catalyst in the control strategy. Define the loss in available exhaust heat experienced with the oxidation catalyst strategy.
- Define final NO_x and CO emissions performance as a function of load using efficient testing methods.
- Investigate the implications of post catalyst O₂ sensor positioning with multiple three-way catalytic elements in series. Tests will be conducted with the post catalyst O₂ sensor located after all TWCs and between the first and second TWC elements.
- Define NO_x, CO, and VOC emissions using test procedure consistent with source testing for permitting in California and CARB 2007 guidance documents. Demonstrate compliance with CARB 2007 limits.
- Participate in a Critical Project Review with the Commission Project Manager

The products will include a laboratory test report (Draft and Final). The reports will include the emissions performance with respect to the CARB 2007 limits as well as descriptions of the air/fuel ratio system control strategy, the hardware employed, and the catalyst strategy. A power point presentation will be prepared summarizing progress through Task 4 for consideration and discussion at the CPR meeting.

Products:

- Draft Laboratory Test Report
- Final Laboratory Test Report
- Overview report for CPR meeting

Due Date: ~~October 31, 2009~~ **October 29, 2010**

TASK 5 FIELD VERIFICATION

The goal of this task is to verify performance of the developed emission systems under field conditions.

The Recipient shall:

- Select two operating CHP sites. Each of these sites will be retrofitted with the enhanced emission control system, diagnostics and alarms.
- Perform tests at each of these sites over a 6 month period alongside on-site semi-continuous emissions measuring systems capable of detecting and documenting deviations in CO and NOx emissions. The nature of any observed deviations will be documented. If appropriate, deviations will be addressed with further investigations either in the laboratory or in the field, with the goal being to learn the root cause of the deviation and modify the system to resolve the issue as appropriate.
- Collect, reduce and assess emission and relevant engine performance data, including air/fuel ratio control system alarms.
- Document field test findings and verify attainment of performance targets in field verification reports.

Products:

- Draft Field Verification Report
- Final Field Verification Report

Due Date: ~~April 30, 2010~~ **January 31, 2011**

TASK 6 TECHNOLOGY TRANSFER ACTIVITIES

The goal of this task is to provide information on the ultra-low emission engine technology to key market participants to enable engine CHP to continue as a technology option in California.

The Recipient shall:

- Prepare a white paper on Internal Combustion Engine (ICE) CHP Environmental Regulations and State Energy Policy which includes:
 - Near-term strategies for continuous compliance and for 2007 CARB
 - Cost implications (or cost/benefit analysis) of various compliance methods and protocols
 - Commercial readiness (current status and timeframe to commercial availability)
 - Linkage of ICE CHP to State Energy Policy
- Prepare a Technology Transfer Plan that explains how the knowledge gained in this project will be made available to the public. Information to be transferred includes, process flow and instrumentation diagrams, key component descriptions, test facility setup, and test results. The plan will identify important CHP market participants active in California. Participants will include:
 - State Government
 - Local air pollution control districts
 - Energy service companies
 - Engine system packagers and manufacturers
 - Emission control equipment manufacturers (i.e., catalysts, air/fuel ratio controls, sensors, etc.)
 - Professional Associations (i.e., ASME)

Prepare technical paper on strategies for controlling Stoichiometric engine emissions to ultra-low emission levels.
- Identify forums and methods to achieve the technology transfer objectives. This will include technical papers and power point presentations at key conferences and workshops that are attended by the market participants.
- Conduct technology transfer activities in accordance with the Technology Transfer Plan. These activities shall be reported in the Monthly Progress Reports. Key elements from this plan shall be included in the Final Report.

Products:

- Draft and Final White Paper and Power Point Presentation on ICE CHP Environmental Regulations and State Energy Policy
- Technical Paper on Control of Stoichiometric Engine Emissions to ultra-Low Levels
- Draft and Final Technology Transfer Plan

Due Date: ~~October 31, 2009~~ **January 31, 2011**